Research Article

International Journal of Advanced Technology and Engineering Exploration, Vol 9(91)
ISSN (Print): 2394-5443 ISSN (Online): 2394-7454
http://dx.doi.org/10.19101/IJATEE.2021.875292

Performance based seismic analysis of RC structural system under earthquake excitation

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Received: 08-December-2021; Revised: 18-June-2022; Accepted: 20-June-2022

Abstract

The most common cause of moment resistant framed constructions failing after an earthquake is soft storey collapse. This work uses performance-based seismic analysis to investigate the building's inelastic seismic response when subjected to earthquake ground motions, as well as to minimize the limitations of the traditional force-based technique. An eight-storey reinforced concrete building located in various seismic zones, situated on various soil types, and containing a masonry infill wall is evaluated using performance-based analysis. Models of plastic hinges are developed to determine the desired performance levels under seismic excitations, with an emphasis on the inelastic response of the buildings considered in this study. Pushover analysis is used to evaluate the seismic performance of building models with varying soft storeys. The performance point is calculated using FEMA 440 equivalent linearization and American society of civil engineers (ASCE) 41-13. The use of nonlinear time history analyses for some prominent earthquakes is also part of the performance-based seismic evaluation. The article illustrates how an increase in soft storey can change the seismic response of a building by reducing vertical rigidity. According to the obtained results, initial hinges are formed at lower-level columns and cross the collapse prevention (CP) level in later steps even before hinges are formed at upper level. As compared to the capacity spectrum method (CSM), displacement coefficient method (DCM) yielded lower seismic response results. Performance based seismic evaluation is compatible with time history analysis.

Keywords

Moment resisting frames, Soft storey, Masonry infill, Performance based analysis, Pushover analysis, Inelastic response.

1.Introduction

Reinforced concrete (RC) structures are being used extensively worldwide due to their affordability and ability to withstand gravity and lateral loads. The present seismic code assumes that structures to be fixed at the bases. But in reality, the soil medium that supports the structure allows some movement leads to reduction in lateral stiffness of the structure [1]. So, randomness in the soil type should be addressed while assessing the seismic performance of the structure to capture the realistic behaviour of the structure under seismic excitation. Historically, seismic design relied on the traditional force-based approach [2, 3]. It has many shortcomings. Using a maximum credible earthquake approach, this approach emphasizes life safety [4]. Structures constructed using this approach, on the other hand, usually reveal more serious damage than expected [5]. Large earthquakes have made it clear that more precise methods for estimating seismic loads on structures are required, which support geometrical nonlinearities and material inelasticity in particular [6]. Therefore, seismic design is moving towards a performance-based approach. Performance-based seismic design (PBSD) allows for the precise understanding of the life risks, property losses, and economic losses associated with future seismic events [7, 8]. PBSD is a generic design philosophy that aims to meet most performance requirements

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during earthquake ground motion [9]. PBSD uses displacements and drifts to express performance levels. The level damage to the structural components related to the displacement of the structural components for the realistic behaviour of the structure [10]. Damage is related to a structure's performance. Displacement based seismic design (DBSD) is a unique structural design approach based on displacement [11]. Pushover analysis (PA) indicates the seismic performance of individual structural components under earthquake through the plastic hinge formation [12].

Challenges or shortcomings of the current seismic analysis are as follows:
The present seismic code is force based. But most of the recent earthquakes show that displacement is the most influencing parameter that controls the seismic performance of the structures. Therefore, performance based seismic analysis comes into picture wherein actual behaviour of the structure is simulated and considered in the study. The randomness of the seismic intensity and soil type neglected in the most of the studies is reflected in the present investigation.

A study was conducted in which the seismic performance of building frames with varying soft storeys (SS) was evaluated. Taking into account diverse soil types, structures are assumed to be placed in various seismic zones. In the study, the seismic performance of case study building frames was projected based on some of the most notable earthquake ground motion records to capture the realistic behaviour of the structural types considered.

Buildings that are seismically unsound because the design does not guarantee the proposed building will meet the objectives set at the outset. For systemic structural protection, performance-based design is required. PBSD techniques have been refined by several studies, resulting in numerous guidelines [13−19]. The purpose of this study is to study the seismic response of a multi-storey building with variable SS reinforced with infill masonry, situated in various seismic zones and under a variety of soil types under some notable realistic earthquakes within the framework of PBSD.

The article is organized in the following manner. Comprehensive review of the present topic is presented in the section 2. Some of the available methods for seismic evaluation presented in section 3. Typical building configurations considered in the present study with geometric details are listed in the section 4. Section 5 provides complete results and comparative discussion of the various seismic parameters under investigation. Overall discussion of the results and analytical investigations carried out in the present study and limitations of the present study is presented in section 6. Concluding remarks and future works are given in section 7.

2.Literature review

With inelastic components, energy-absorbing components, and ductile components, among others, the structure should be capable of withstanding a major earthquake. This is where PBSD comes in [20]. PBSD provides a reasonable assessment of structural behaviour in case of a specific or generalised seismic ground motion. Although some lateral force resistance is provided by the design regulations, this force is far less than what a building might encounter during a hypothetical catastrophic earthquake [21].

Some of the challenges with using nonlinear static approaches to determine the performance of RC frames were examined [21]. Various lateral load patterns were applied to 15-moment resisting frames (MRF) as per IS: 456-2000 [22]. Using seismic response data, it was found that the Indian seismic code did not specify the basic time period and response modification factor.

Inelastic seismic responses of RC structures were simulated using nonlinear static and time history analyses [23]. Finite element models accurately depict a building's nonlinear behaviour. PA has been determined to be more accurate than the multi-degree of freedom (MDOF) analysis in evaluating seismic performance on a multi-storey RC building in Zone V. This can be proven by comparing it to the MDOF analysis.

A four-storey RC structure was evaluated for seismic performance using federal emergency management agency (FEMA) 273 [24] plastic hinges designed and built according to the specified rules. The PA method evaluated each component of a building, its potential mode of failure, and the building's final state after it has been subjected to a predetermined amount of lateral stress.

Using nonlinear static analysis, the seismic efficiency of a nine-storey building in seismic Zone III was determined [25]. Based on the stress strain models defined in IS 456:2000, plastic hinges were developed using Visual Basic software. Auto hinges found to be less ductile than the hinges in the building model. The base force at performance point (PP) is lower than the default hinge. So, it's crucial to model plastic hinges with user-defined hinges for a thorough safety assessment.

Using extended three-dimensional analysis of building systems (ETABS), seismic response of four and eight-storey buildings was investigated with and without the ductility effect [26]. Infill walls of unreinforced masonry (URM) affected the overall behavior of the structures. In addition, the ultimate displacement drops dramatically as the storeys increase. Ductile structures perform substantially better than non-ductile buildings.

Real ground motion records were used to explore the dynamic response of regular and vertically irregular structures [27]. The ground motion records from 130 sets in 13 different groups were chosen using Euro code 8 to study the effect of ground motion number on the structural seismic response. According to the nonlinear results, stable structural responses were obtained when the actual ground motion exceeded 7, but conservative results appeared when the actual ground motion was limited to 7.

A study examined the inelastic response of five and six-storey residential buildings to ground vibrations [28]. Dynamic analyses and PA were used to capture the seismic demand, using a system approach that considered material quality. The study found that ground motion near faults had a greater impact on seismic reactions. The study also revealed that brittle materials have an impact on structure behaviour. Poor quality materials and craftsmanship, as well as an absence of codal standards, are largely responsible for this.

Seismic response of a mid-rise building was studied using ground motion data and local soil conditions [29]. A database containing the damage state of individual structural components and infill walls was developed to examine seismic performance in 140 such buildings. The study found that structural member deficiencies, construction quality, and the infill wall all affected structural performance.

Buildings resting on sloping ground in different configurations were analysed using time history analysis [30]. In this context, ETABS software analysed some time history data from India. Step back and setbacks are common layouts for shear walls. It was found that structures with internal shear walls performed better. Set back and step back structures performed better than an H shape structure without a shear wall.

ETABS and structural analysis and design (STAAD) software were used to measure seismic performance of a 25-story building [31]. Using the response spectrum method, the single degree of freedom (SDOF) system was displayed. The efficacy of both software is demonstrated in the study.

The seismic vulnerability of framed buildings with varying setbacks was examined [32]. Nonlinear static analysis was used to create fragility curves for seismic factors beyond a certain threshold. Study findings indicate that vertical irregularity plays a key role in assessing the susceptibility of structures. With increasing setback value, the building's capacity decreased, indicating increased fragility.

An investigation of the seismic response of three distinct structures situated on varied soil types was conducted [33]. Three pounding scenarios were analysed with varying seismic gaps. Square root of sum of squares (SRSS) method was used to calculate the absolute total displacements. Seismic gap and soil type have the greatest impact on seismic response of the case study buildings.

2.1Summary of literature review

From the comprehensive literature review carried out in the section 2, major challenges identified as follows

- Discontinuity in the floor continuity in the form of soft storey or weak storey provision to be addressed.
- Performance based seismic evaluation overcomes the conservatives in the traditional approach followed by the various codes of practice.
- The nonlinear static analysis addresses the PP in the building configurations associated with various performance levels.
- For realistic prediction of structural seismic responses, notable earthquake data should be implemented by considering the seismic severity variation and type of soil consideration.
- Influence of variable soft storey effect with continued or discontinued masonry infill.

The above parameters are highlighted in the present study to fill the research gap or fulfill the objective of study to capture complete seismic responses of various associated models taking into account various points listed.

3.Methods

3.1Methods for performance based seismic evaluation

A force-based method is used in traditional seismic design to provide maximum life protection in the event of an earthquake. Thus, most codes do not mention performance factors other than personal safety [34].

In order to evaluate the seismic performance of the building, the inelastic behaviour of a structure is taken into account [35]. The guidelines recommend four research strategies to assess seismic demand. The first two procedures are static and dynamic based on force, whereas the other two are static and dynamic based on displacement [36−38].

Many approaches have been offered to determine the performance of a structure in PBSD guideline publications. There are three main factors involved in these methods: (1) Capacity (2) Demand (3) Performance. Performance based seismic evaluation (PBSE) recommended four research methodologies for estimating seismic demand. In two, linear static and dynamic procedures are used, and in the other two, nonlinear static and dynamic procedures are used [38]. By using PBSD, structures are more seismic load-carrying and cost-effective. The PBSD obtained using the above methods also meets the requirements for immediate occupancy and life safety in earthquakes of various magnitudes [39].

3.2Non-linear Static analysis

As the name implies, static loads are applied sequentially to the structure until it reaches its final state. Floors of an inelastic structure are subjected to a progressively rising lateral force pattern, matching earthquake-induced forces in PA (after they have been filled with gravity loads).

The capacity spectrum method (CSM) and displacement coefficient method (DCM) are the PBSE procedures accredited in the PBSD guidelines. CSM compares a structure's capacity with its demand. The DCM method calculates target displacement the simplest way. The target displacement refers to the displacement of the characteristic node, which is usually at the top. The DCM technique uses modifying coefficients to calculate target displacement from peak elastic displacement, as described by the American society of civil engineers (ASCE) 41-13.

Figure 1(a) shows a schematic illustration of the CSM and DCM procedures, with a clear representation of the PP. PP is at the junction of these two curves, which may be found by superimposing capacity and demand spectrums. *Figure 1(b)* displays a DCM technique approximation.

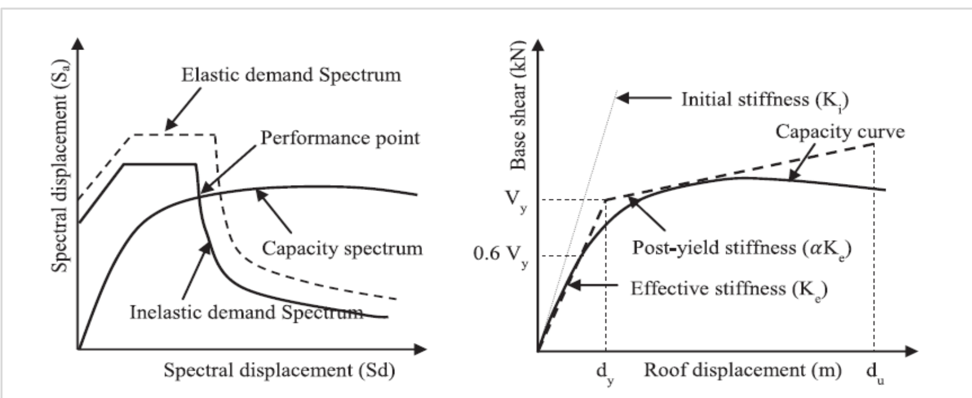


Figure 1 a) CSM procedure b) DCM procedure

3.3Non-linear dynamic analysis

If real earthquake data is available, nonlinear time-history analysis is regarded as the most precise method for predicting the behaviour of structures subject to high levels of seismic excitation. The time-history method can be used to evaluate both linear and nonlinear dynamic structural responses.

3.4Plastic Hinge modelling approach

A hinge represents a member's localized force-displacement link over elastic and inelastic phases. User-defined or default plastic hinges can be used in software programmes that do PA based on applied technology council (ATC-40) and FEMA-356 requirements. At the ends of the beams, Flexural M3 hinges are used, and at the ends of the columns, P-

M2-M3 hinges. Flexural hinges, such as the one shown in *Figure 2* [40], reflect the moment-rotation relationship of a beam. Hinges can be modeled at cross-sectional or member levels. Axial hinge, shear hinge, and flexural hinges are shown in *Figure 3*.

Figure 2 depicts a force – displacement of a plastic hinge that demonstrates the nonlinear static PA performance levels.

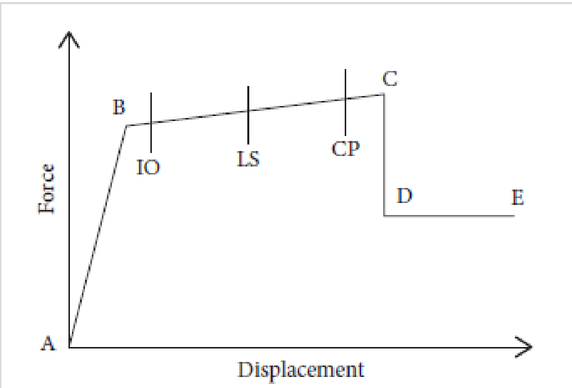


Figure 2 Force- displacement relationship of a plastic hinge with performance levels

The usual hinge patterns associated with various force and bending mechanisms, such as flexure, shear, and axial hinges, are shown in *Figure 3*.

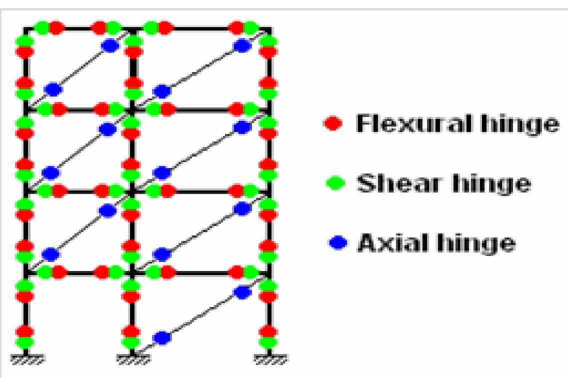


Figure 3 Typical locations of hinges in a structural model

3.5Effect of masonry infill wall

For RC frame structures in developed countries, masonry walls are used. It has been determined that masonry infill walls play an important role in RC frame buildings' lateral stiffness, resilience, and overall ductility [41−47]. IS: 1893 [48] treats masonry infill walls as equivalent diagonal struts (EQVT). The same is employed in the present study also. Infill wall and EQVT have the same thickness. The EQVT width must be calculated as follows (Equation 1):

$$Wds = 0.175\ \alpha h^{-0.4}\ Lds \qquad (1)$$

Where,

$$\alpha h = h \left(\sqrt[4]{\frac{Em\ t\ \sin 2\theta}{4\ Ef\ Ic\ h}}\right) \qquad (2)$$

Where,

The moduli of elasticity of the masonry infill material and the RC moment resisting frame are E_m and E_f, respectively,

I_c - the next column's moment of inertia

t - Infill wall thickness

θ - The angle formed by the diagonal strut with the horizontal

In a typical multistorey building, *Figure 4* depicts the corresponding diagonal strut mechanism connected with brick infill wall mechanism.

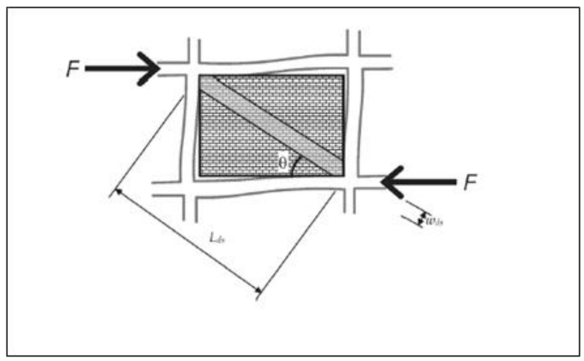


Figure 4 Equivalent diagonal strut (EQVT) of masonry infill wall

3.6Soft-storey effect

It is defined as a weak or soft storey if its stiffness or resistance is less than or equal to the storey below or above it [49−51]. Structures with soft storeys have a lot of open space. An earthquake can damage this structural irregularity on any storey. Previous earthquakes revealed concrete crushing, reinforcement buckling, and other types of failure in open storey buildings [51, 52].

4.Building example

ETABS is used to model three-dimensional RC moment-resistant frames. Structure is divided into four bays, each measuring 4 metres long and 3 metres high. The building is symmetric in both orthogonal directions to avoid torsional impact. *Table 1* shows the sectional properties of the building components. Unit weights of concrete and masonry shall be 25 and

20 kN/m2, respectively. Concrete and masonry have moduli of elasticity of 25000 MPa and 2255 MPa, respectively. Wall loads are considered solely for outer perimeter beams. For each MRF, the desired displacement was 2% of the frame's height. As a result of the stiffness of the building, the walls are treated as struts equivalent to IS: 1893. *Figure 5* displays the three dimensional representation of a typical framed building modelled in ETABS software.

The building is analyzed in seven different models (*Figure 6*). There are the following:

1st Model: Building frame model with EQVT Strut ([1] regular)

2nd Model: Building frame model with EQVT Strut – Soft storey at Ground floor ([2] GF SS)

3rd Model: Building frame model with EQVT Strut – Soft storey at Ground and first floor ([3] 1F SS)

4th Model: Building frame model with EQVT Strut – Soft storey at Ground, first and second floor ([4] 2F SS)

5th Model: Building frame model with EQVT Strut – Soft storey at Ground, first, second and third floor ([5] 3F SS)

6th Model: Building frame model with EQVT Strut – Soft storey at Ground and second floor ([6] G & 2F SS)

7th Model: Building frame model with EQVT Strut – Soft storey at first and third floor ([7] G & 3F SS).

The geometrical features and specifications connected with the numerous building examples listed in section 4 are listed in *Table 1*. *Table 2* lists the typical properties of moment resistant frames used in nonlinear static and dynamic analysis. *Figure 6* depicts an elevation view of all of the models specified in section 4.

Table 1 Design parameters

No. of Storey	8
Bay	4×3m
Size of Column	400×400mm
Size of Beam	230×400mm
Thickness of Slab	150mm
Reinforcement Grade	Fe 500
Concrete Grade	M 25
Dead Load (DL)	Self-Weight
Live Load (LL)	3 kN/m^2
Floor Finish (FF)	1 kN/m^2
Response reduction factor	5
Zone	III

Table 2 Characteristics of the studied example MRFs

Type of analysis	MRFs	Soft stories at	Beam size	Column size	Site
Non-linear Static Analysis	1st Model	-	230×400 mm	400×400 mm	Zone III,IV,V and soil type 1,2,3
	2nd Model	G			
	3rd Model	G, 1			
	4th Model	G, 1,2			
	5th Model	G, 1,2,3			
	6th Model	G, 2			
	7th Model	1,3			
Non-linear Dynamic Analysis (FNA)	1st Model	-	230×400 mm	400×400 mm	Ground data matched for Zone III and soil type 2
	2nd Model	G			
	3rd Model	G, 1			
	4th Model	G, 1,2			
	5th Model	G, 1,2,3			
	6th Model	G, 2			
	7th Model	1,3			

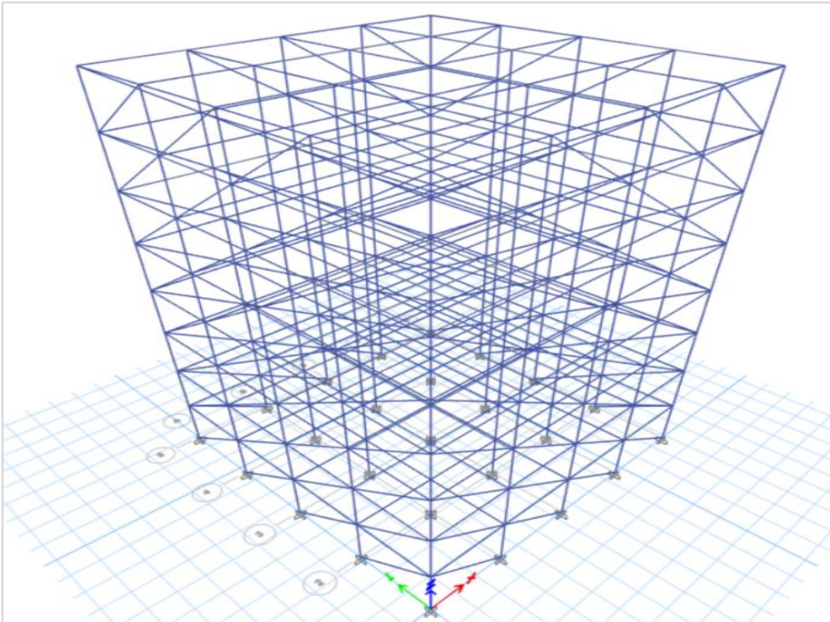
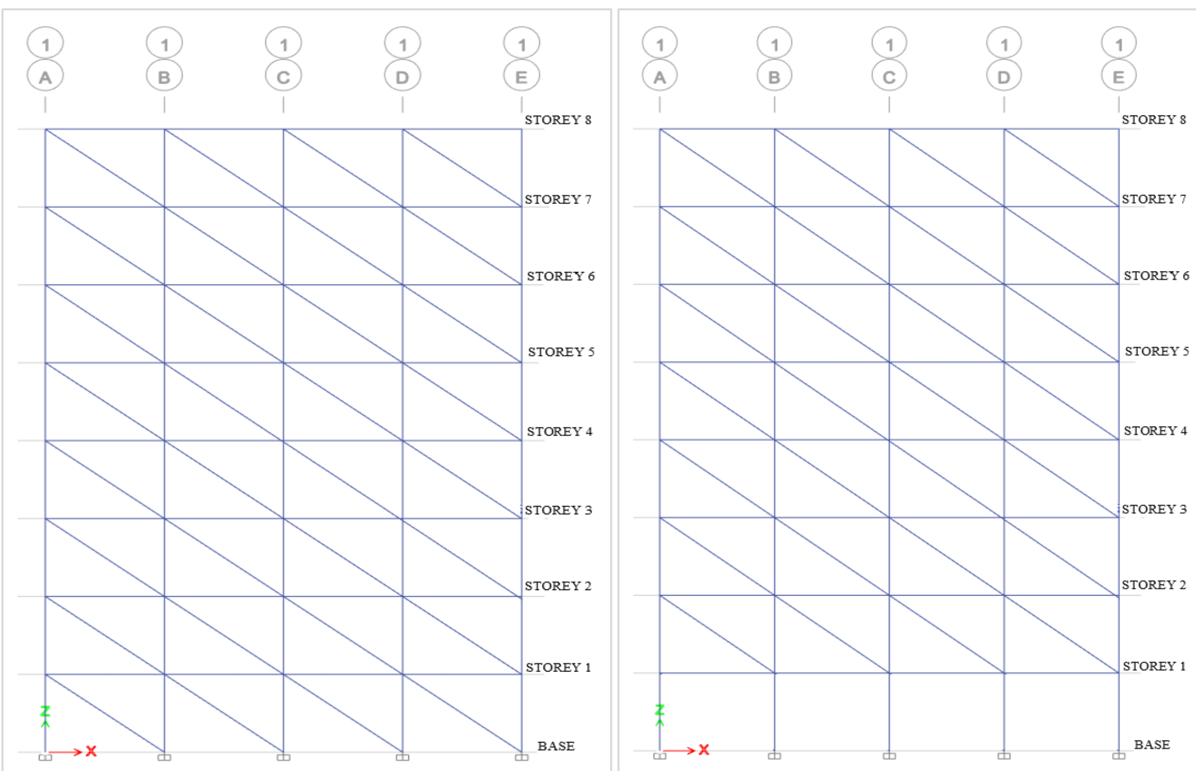
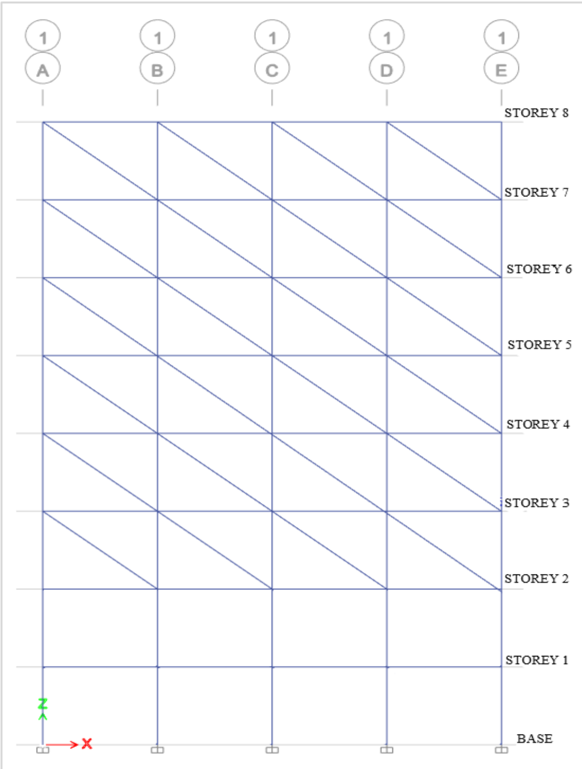


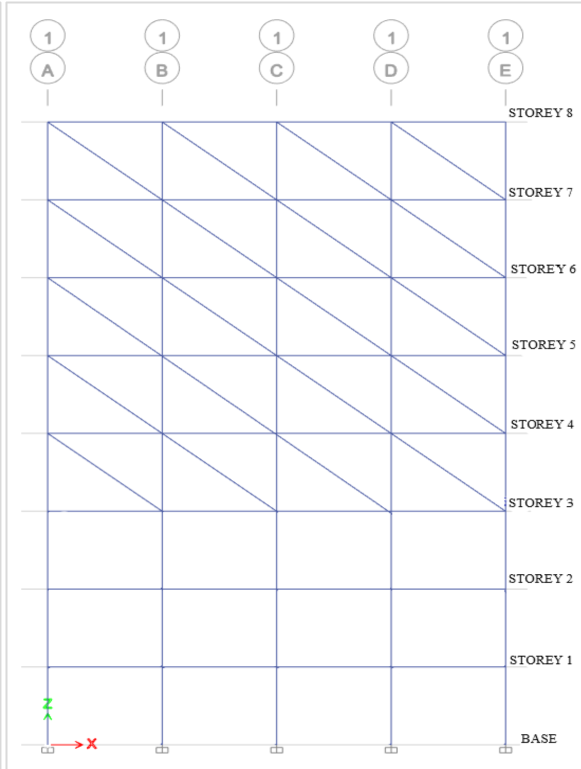
Figure 5 Regular 3D *Model*



(a) (b)


1
A
1
B
1
C
1
D
1
E
STOREY 8
STOREY 7
STOREY 6
STOREY 5
STOREY 4
STOREY 3
STOREY 2
STOREY 1
BASE
Z
X

(c)


1
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E
STOREY 8
STOREY 7
STOREY 6
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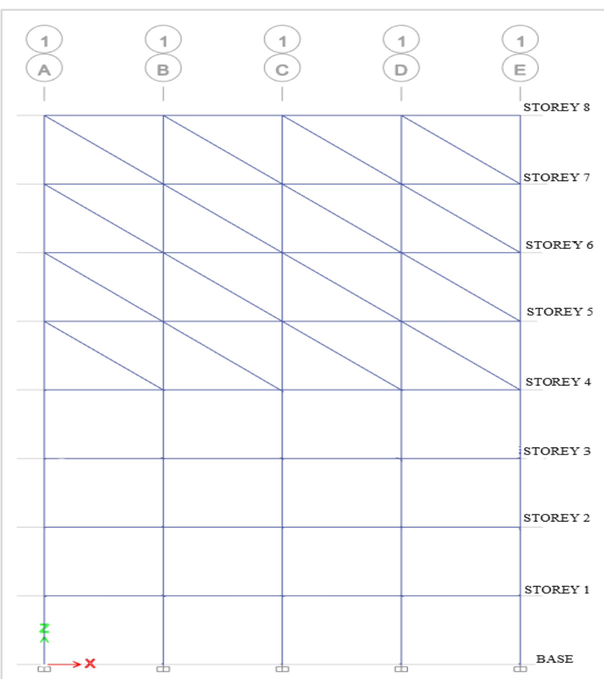
STOREY 4
STOREY 3
STOREY 2
STOREY 1
BASE
Z
X

(d)


1
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STOREY 7
STOREY 6
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STOREY 4
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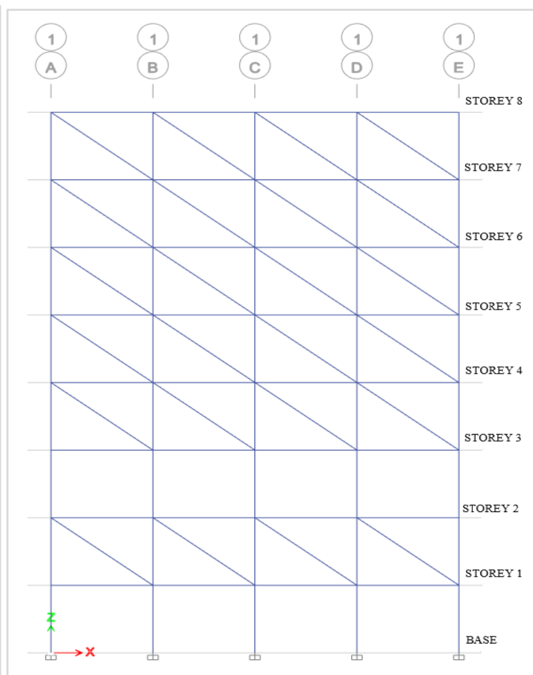
STOREY 1
BASE
Z
X

(e)


1
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STOREY 8
STOREY 7
STOREY 6
STOREY 5
STOREY 4
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STOREY 1
BASE
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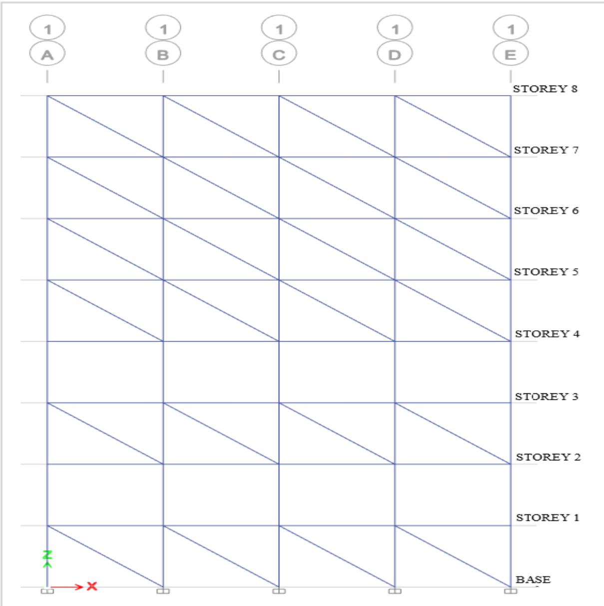
(f)



(g)

Figure 6 Elevation view of (a) 1st Model (b) 2nd Model (c) 3rd Model (d) 4th Model (e) 5th Model (f) 6th Model and (g) 7th Model

5.Results

5.1Non-linear Static analysis results

ETABS software performs a PA for default hinges. PA accounts for fractured sections of beams and columns using section modifiers. Beams and columns have moment of inertia reduction factors of 0.35 and 0.7, respectively.

5.1.1Roof displacement and Base Shear at performance point based on hinge pattern

FEMA 440 Equivalent Linearization was used to calculate base shear and roof displacement at the PP point and ASCE 41-13 to calculate target displacement. In *Table 3*, base shear and displacement are compared to numerous RC frame models using FEMA 440 EL and ASC 11-13 methodologies. Increasing soft stories decreases base shear and increases displacement values.

The force, displacement and hinge formation at different levels of the Regular RC frame located in zone III and soil type 2 are given in *Table 4*. The model has PP of 3180 in base shear and displacement of 43.98 mm, which is below step 2. Step 2 shows 832 hinges within the elastic range (A-B) and 208 hinges below the Intermediate level (A-IO). Base force and displacement are calculated using FEMA 440 Equivalent Linearization.

Table 4 provides a clear example of the number of hinges formed at various performance levels associated with the damage scenario.

Table 3 Base shear and roof displacement at performance point

Frame model	Performance point -equivalent linearization FEMA 440 [15]		Target displacement - ASCE 41-13 [4,5]	
	Shear @ PP (KN)	**Displacement @ PP (mm)**	**Shear (KN)**	**Target displacement(mm)**
1st Model	3180.93	43.98	2430.50	33.33
2nd Model	2678.39	46.5	2278.65	35.73
3rd Model	2511.33	52.03	1936.27	39.65
4th Model	2195.67	55.52	1730.34	43.24
5th Model	2081.06	60.83	1592.12	45.56
6th Model	2358.24	44.57	2038.23	38.32
7th Model	2682.87	53.82	1936.23	38.26

Table 4 Stepwise Base force and Monitored displacement and formation of hinges in different level

Step	Monitored displacement MM	Base force KN	No. of Hinges A-B	B-C	C-D	D-E	>E	A-IO	IO-LS	LS-CP	>CP	Total
0	0	0	1040	0	0	0	0	1040	0	0	0	1040
1	24.462	1804.91	1039	1	0	0	0	1040	0	0	0	1040
2	74.357	5322.01	832	208	0	0	0	1040	0	0	0	1040
3	89.966	6295.05	789	251	0	0	0	1035	2	0	3	1040
4	89.967	6294.87	789	251	0	0	0	1035	2	0	3	1040
5	90.012	6297.85	789	251	0	0	0	1035	2	0	3	1040

In *Figure 7*, the FEMA 440 pushover curve for a regular building configuration is shown. Curve illustrate the capacity and demand for seismic spectral acceleration for a typical framed structure.

According to ASCE-41, *Figure 8* shows the variation of base shear with displacement criteria. In terms of displacement, this curve shows a typical framed structure's capacity and demand.

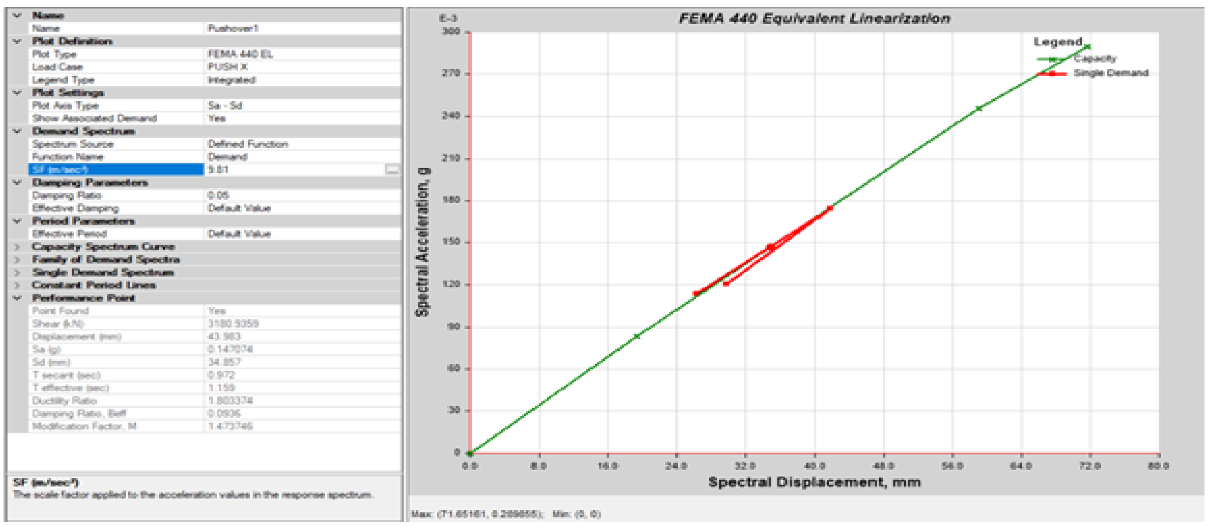


Figure 7 Pushover curve for regular building-FEMA 440 EL

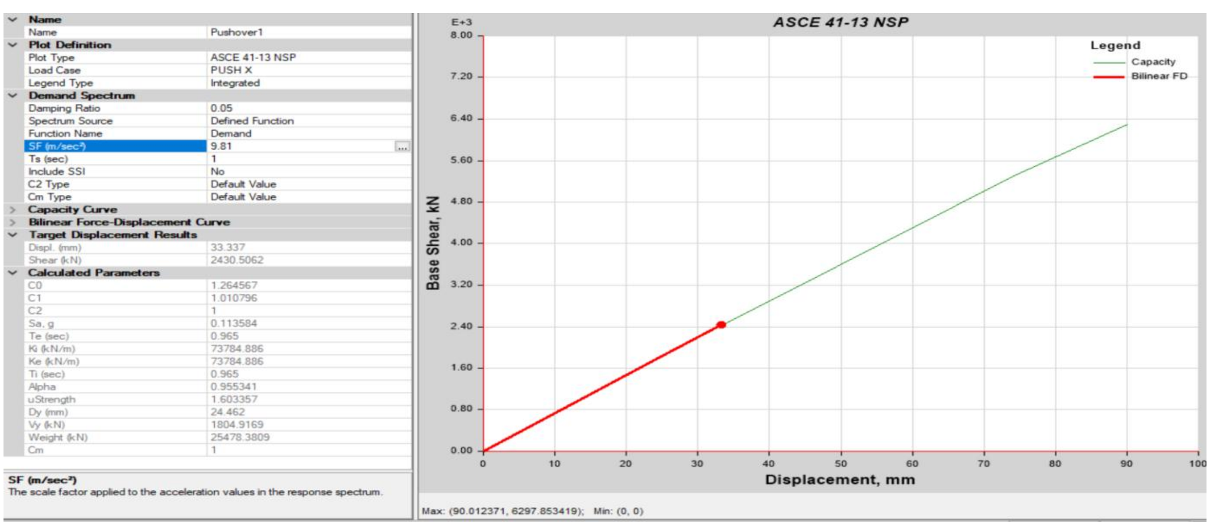


Figure 8 Base Shear Vs displacement regular building- ASCE 41-13

5.1.2Roof displacement and base shear at performance point for various seismic zone and soil type

As shown in *Figure 9*, *Figure 10*, and *Figure 11*, the seismic base shear varies with displacement at the PP for the building layouts evaluated in the study, located in seismic zones III, IV, and IV on soil type 1. FEMA 440 and ASCE norms were followed in the study. As a result, FEMA requirements produce slightly greater base shear results than ASCE guidelines. Increased soft storey levels up to two and three stories yielded higher displacement values compared to the standard building model and models with alternate floors. Observe that as the seismic zone increases, the magnitude of the earthquake may increase, resulting in larger displacements and base shear.

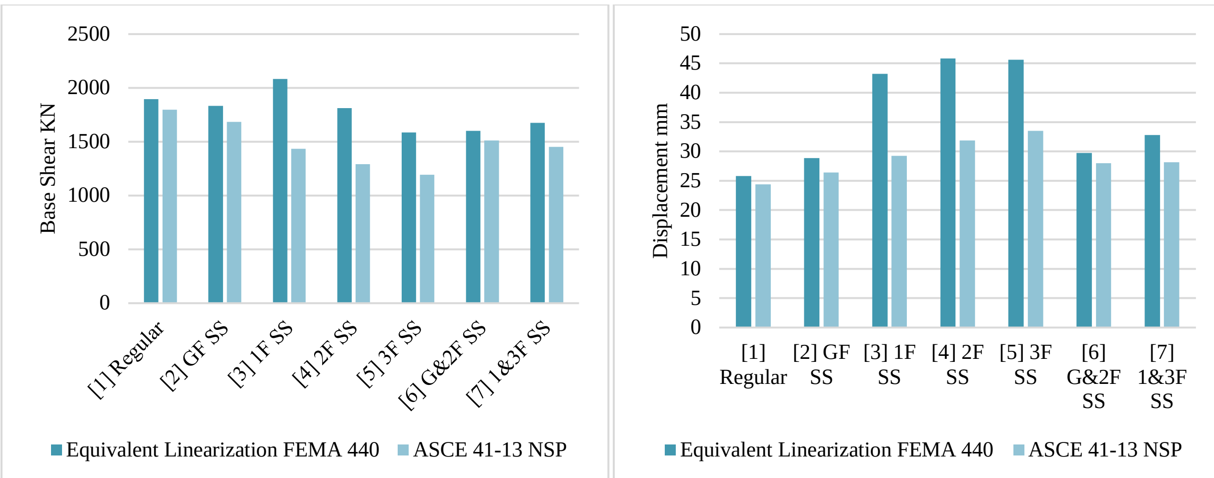


Figure 9 Base shear and displacement at performance point – Zone III, Soil type 1

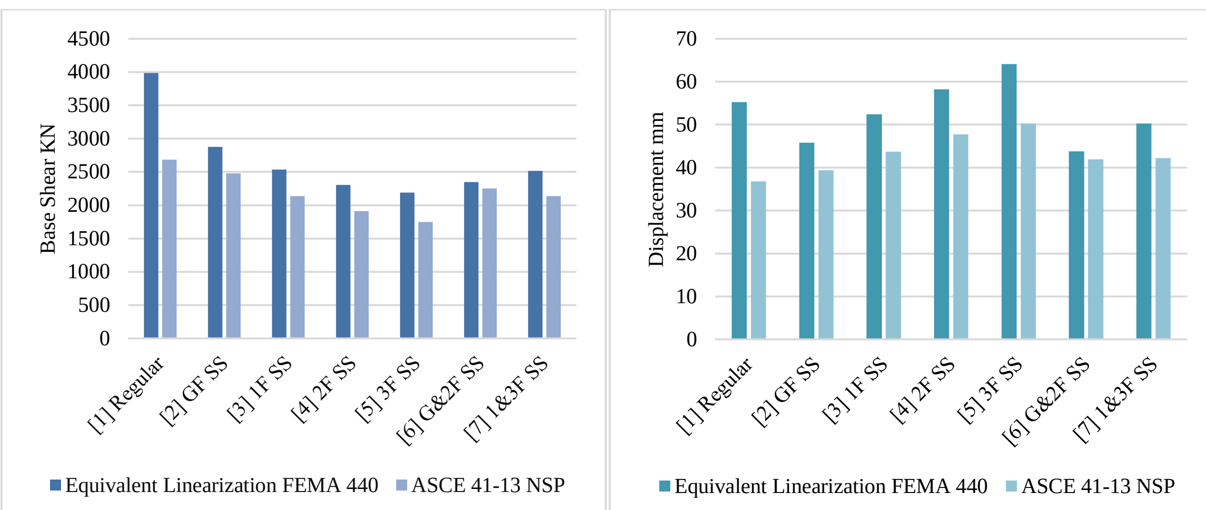


Figure 10 Base shear and displacement at performance point – Zone IV, soil type 1

Various building layouts evaluated in the study, located in seismic zones III, IV, and IV, resting on soil type 2, are illustrated in *Figures 12*, *13* and *14.* As per FEMA 440 and ASCE standards, the study's findings are presented. FEMA standards produce slightly better results than ASCE guidelines for base shear. Increased soft floor level up to two and three stories resulted in larger displacement values than the standard building model. Graphs show that increased seismic zones can lead to an increase in earthquake severity, leading to higher base shear and storey displacement.

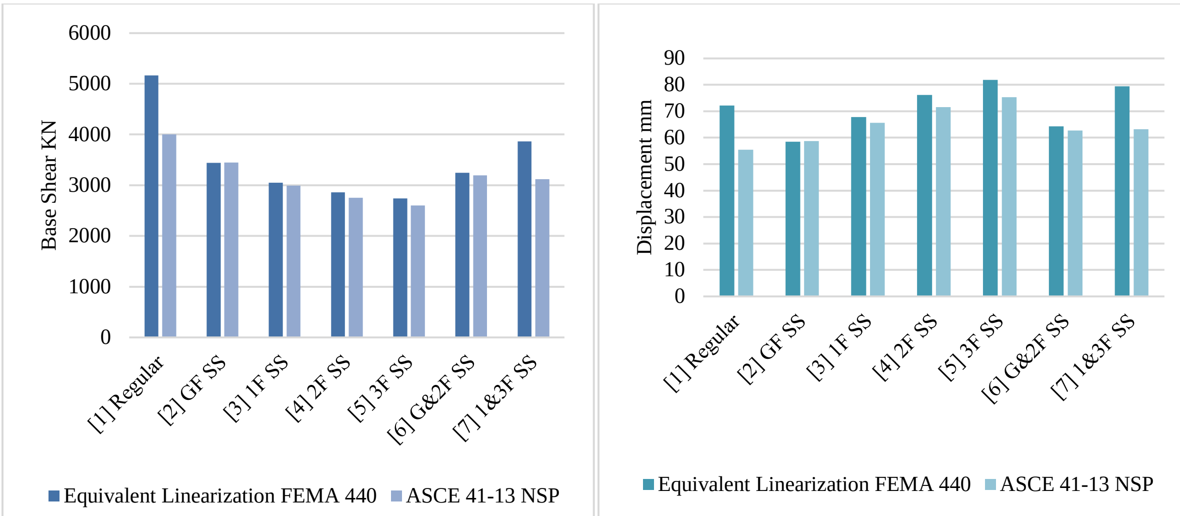


Figure 11 Base shear and displacement at performance point – Zone V, Soil type 1

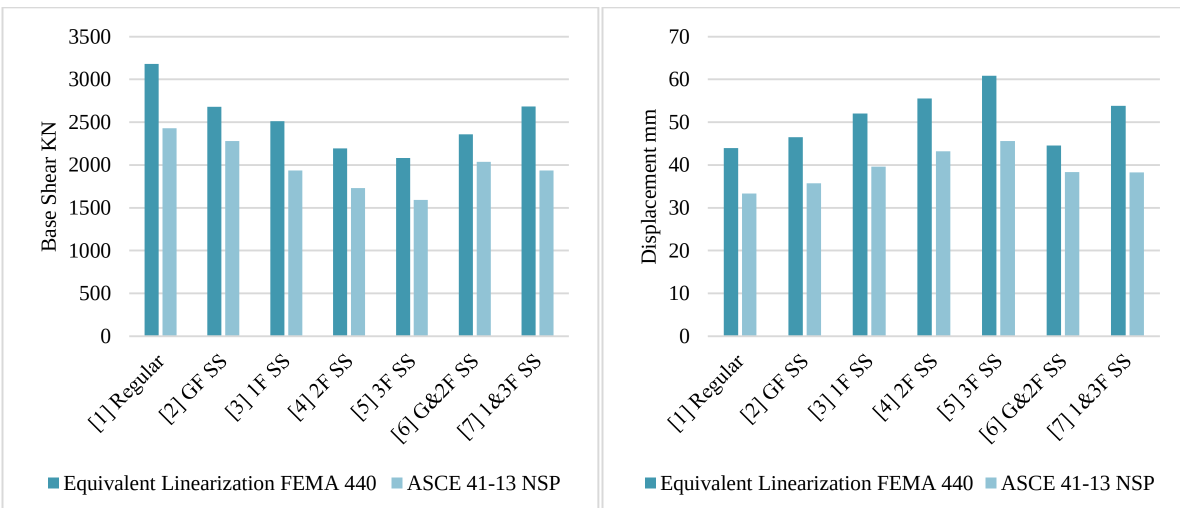


Figure 12 Base shear and displacement at performance point – Zone III, soil type 2

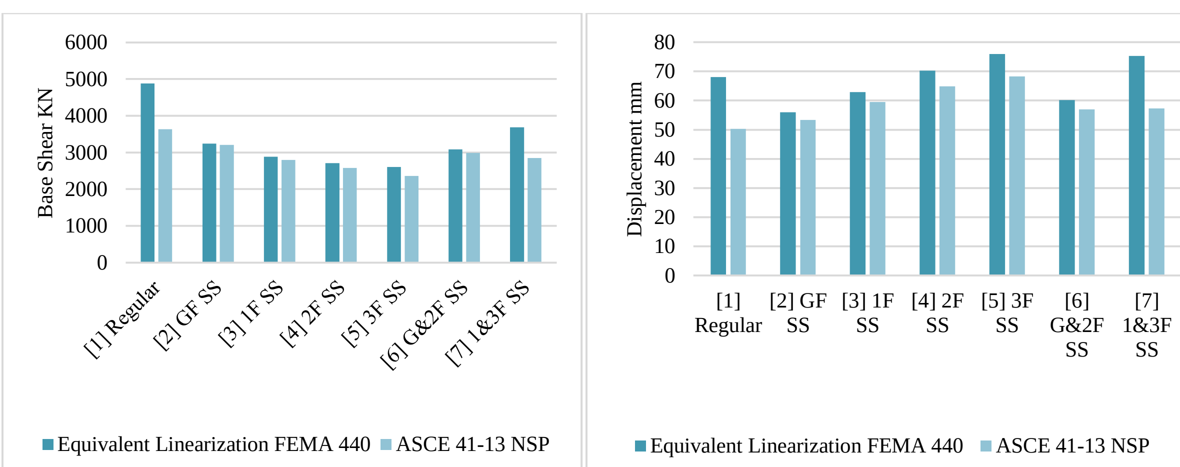


Figure 13 Base shear and displacement at performance point – Zone IV, soil type 2

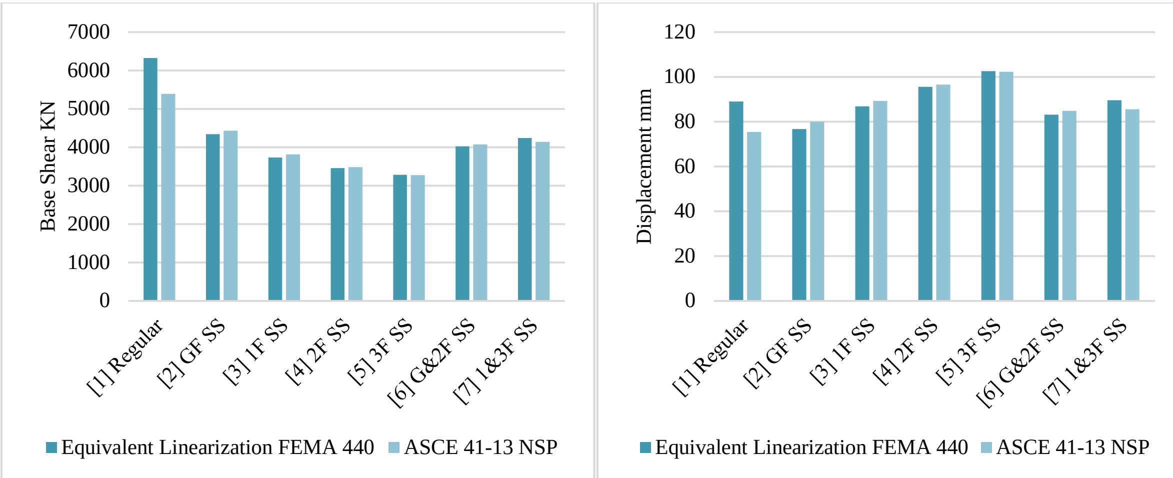


Figure 14 Base shear and displacement at performance point – Zone V, soil type 2

Building layouts in seismic zones IV and IV resting on soil type 3 are illustrated in *Figures 15* and *16*, showing how seismic base shear changes as displacement increases at the PP. FEMA 440 and ASCE norms were followed in this study. Compared to ASCE guidelines, FEMA requirements produce a bit higher base shear results. Increased soft storey levels up to two and three stories resulted in larger displacement values than standard building models or models with alternate floor soft storey provisions. In the graphs, it can be noted that an increase in seismic zone leads to an increase in earthquake severity as well as base shear. MRF of zone V and soil type 2 has the best results with a base shear of 6323 kN and displacement of 88.98 mm. In zone V and soil type 3, MRFs receive no PP.

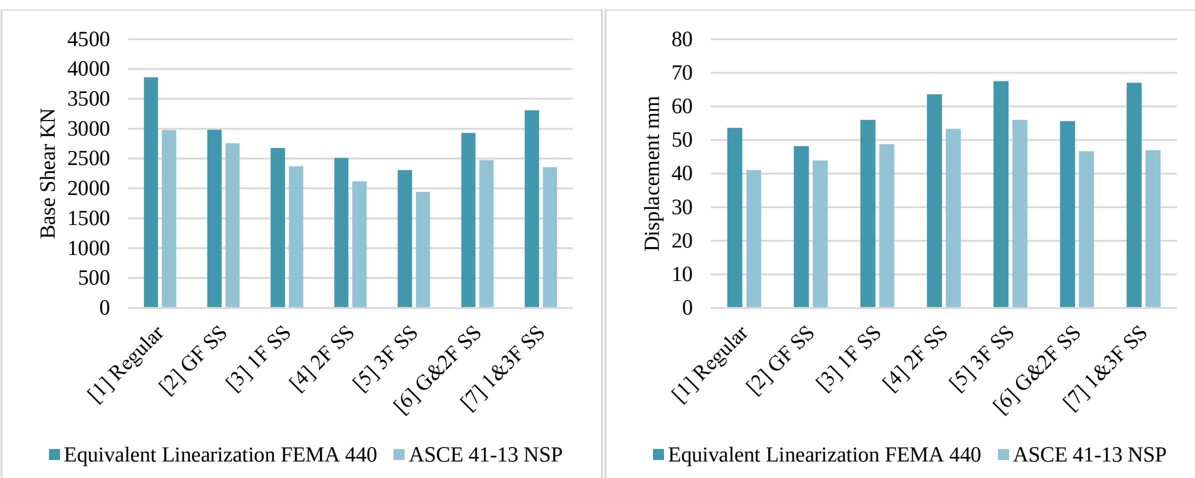


Figure 15 Base shear and displacement at performance point – Zone III, Soil type 3

5.1.3Comparison of maximum roof displacement for various models in different seismic zone and soil type

As demonstrated in *Figure 17*, *18* and *19*, displacement narratives are depicted for different zones and soil types. Storey displacement values increase as the number of soft stories increases. Compared to stories with masonry infill walls, soft storey displacement is larger due to lower rigidity. In the 1&3F SS zone V, type 2 model, the maximum displacement is 82.57mm.

For comparison, *Figures 17*, *18*, and *19* show storey displacements of various building layouts, located in seismic zones with different types of soil. From the figures, it can be seen that storey displacement increases when the seismic zone is shifted. The introduction of soft storey was found to increase displacement compared to conventional models and models with alternate floors of soft storey. Large open areas and soft storeys could be responsible for the lack of storey stiffness.

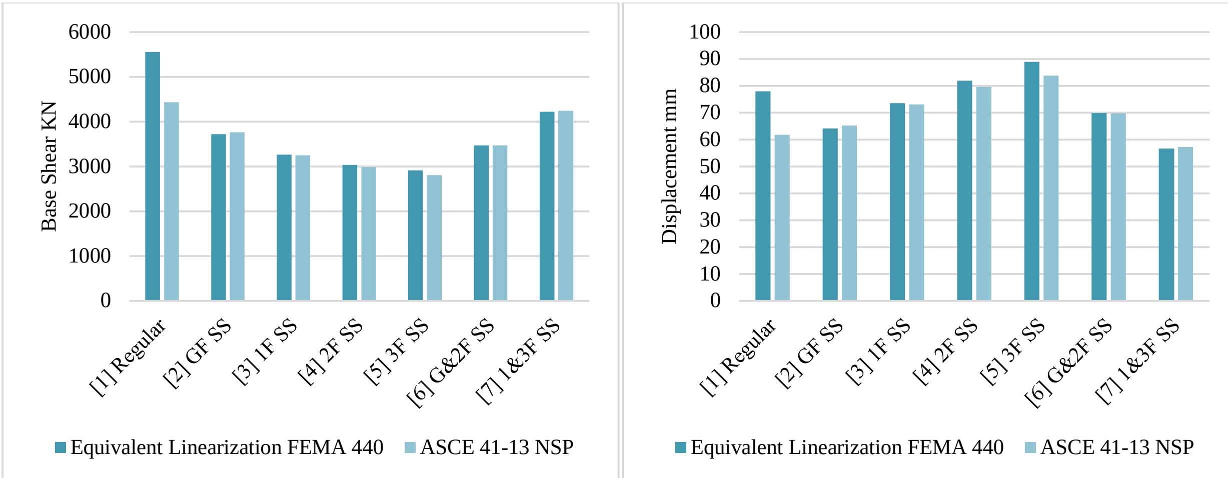
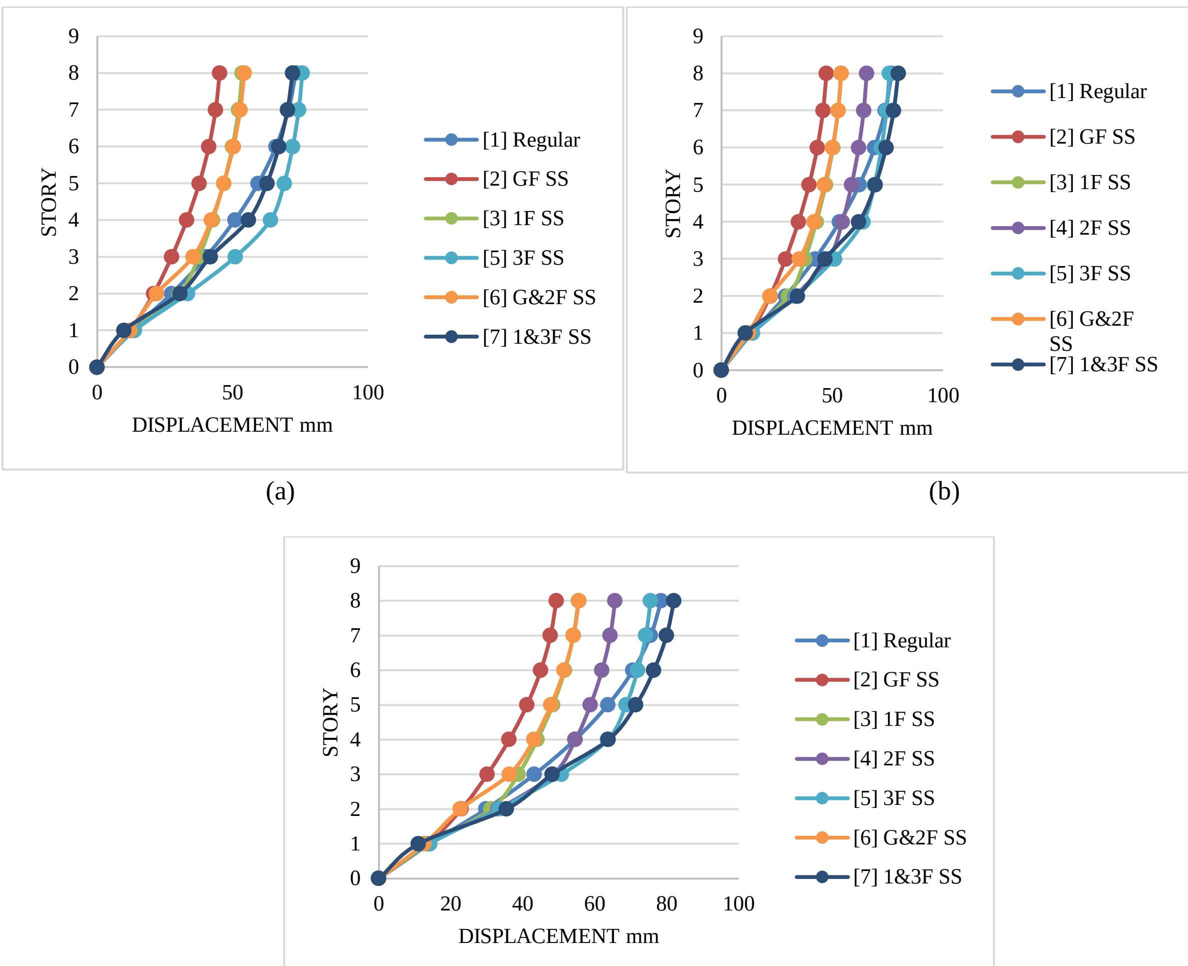
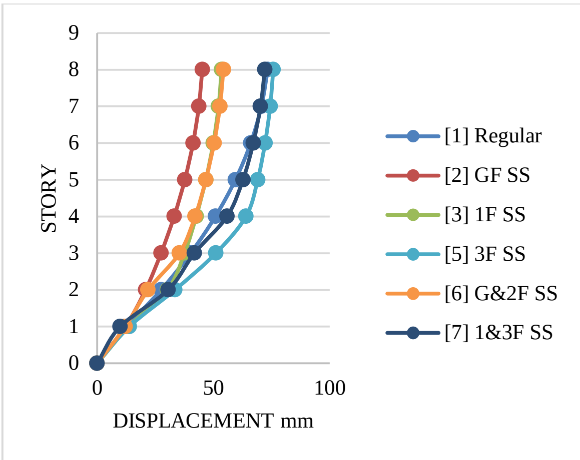


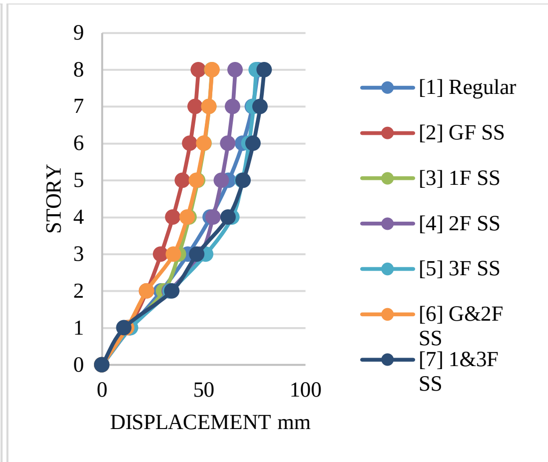
Figure 16 Base shear and displacement at performance point – Zone IV, soil type 3



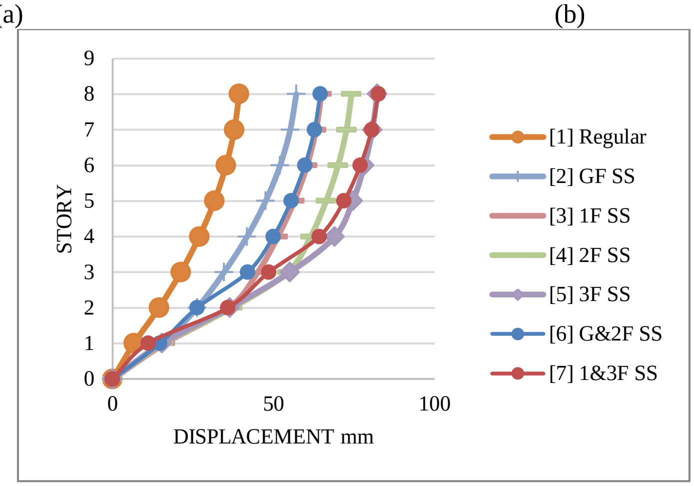
(c)

Figure 17 Storey displacement in zone III, Zone IV and Zone V for soil type 1



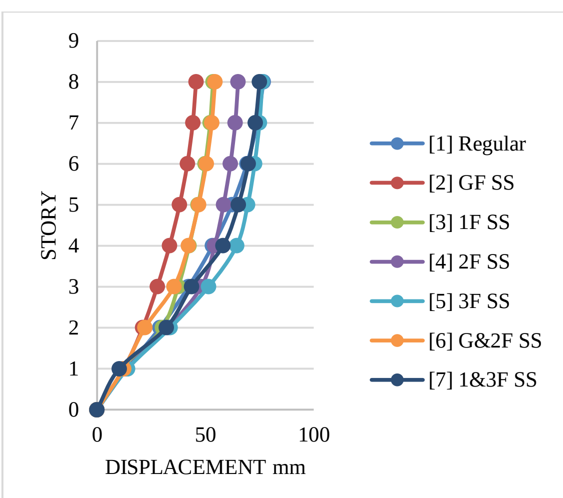


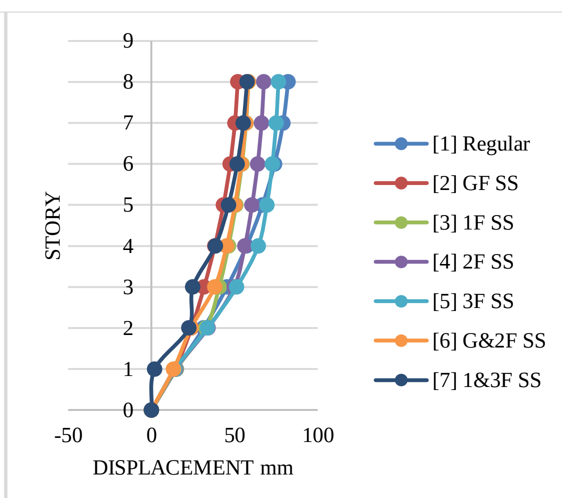
(a) (b)



(c)

Figure 18 Storey displacement in zone III, Zone IV and Zone V for soil type 2





(a) (b)

Figure 19 Storey displacement in zone III, Zone IV for soil type 3

5.1.4 Comparison of maximum storey drift for various models in different seismic zone and soil type

Figures 20, 21, and *22* illustrate patterns of storey drift for several building layouts evaluated in the study, located in diverse seismic zones and with varying soil types. The inter-storey drift in ductile MRFs will be uniform, but not along the building's height. Base soft storey drift is twice as large as top stories. Inter storey drift is significant in the model with alternate soft storey (1&3F SS). The maximum drift was 0.008249 in the 1&3F SS zone 5, soil type 2 model. As seismic zone parameters changed, storey drift rose with earthquake severity. Its value increases if the soft storey provision is continuous for more than one floor and alternate floors. This may be due to the fact that storey drift is related to the displacement of particular floors to higher or lower levels. Consequently, when compared to normal and other building models, the absence of storey stiffness combined with wide open spaces leads to higher storey drifts.

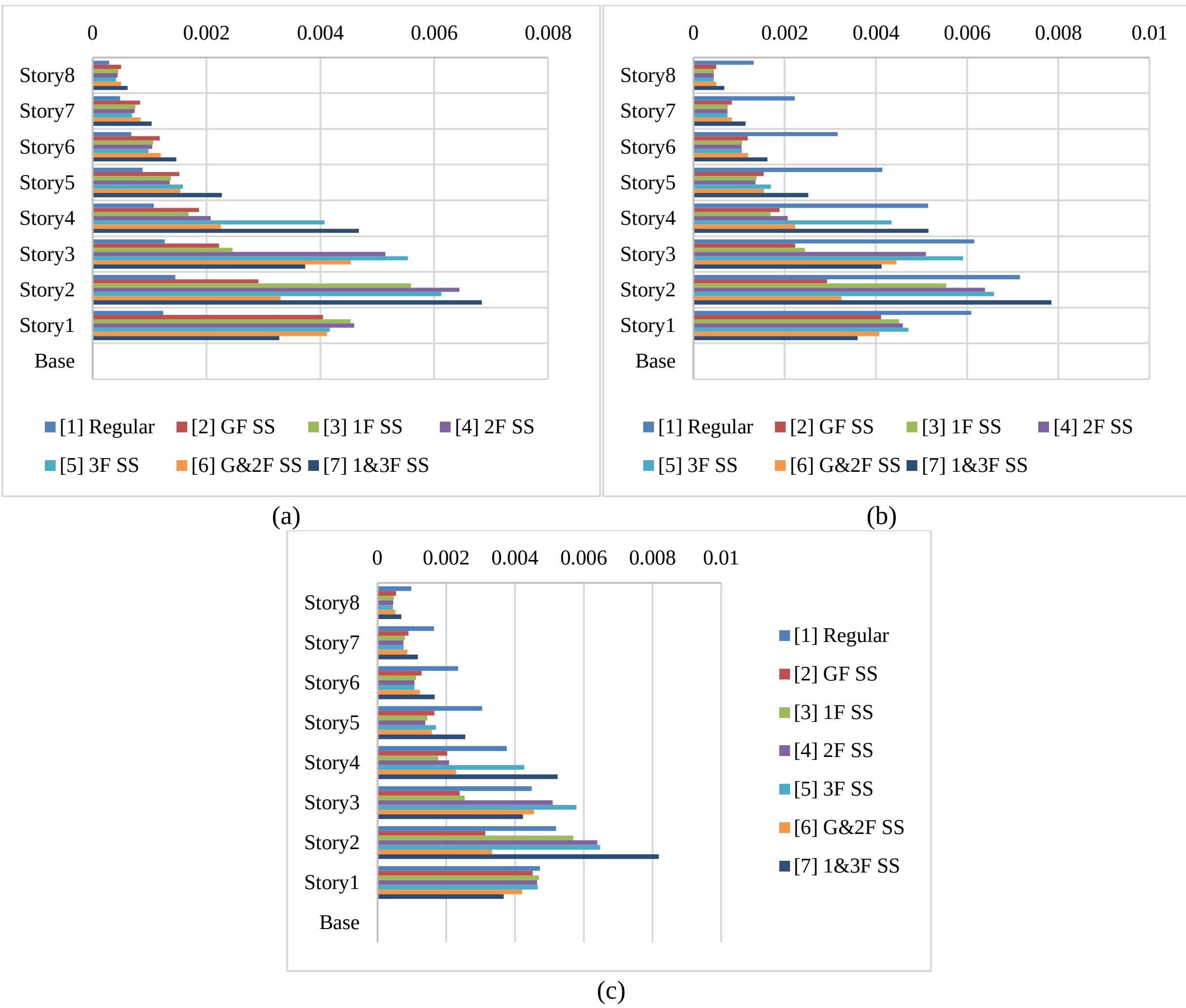
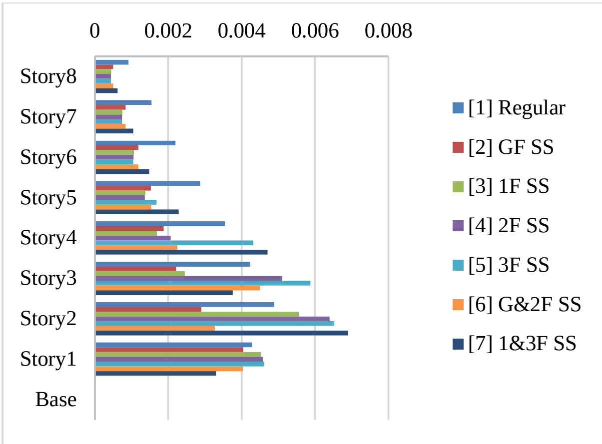


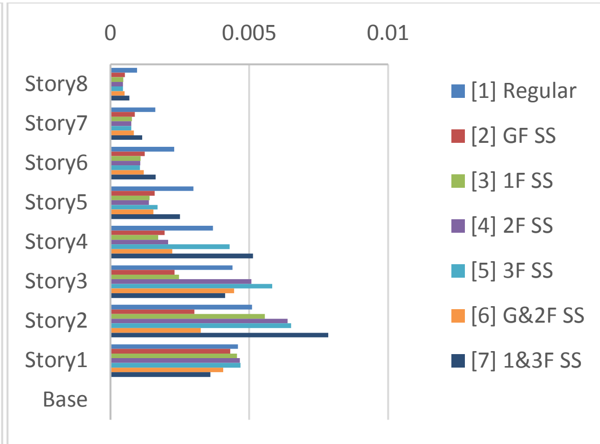
Figure 20 Storey drift in zone III, Zone IV and Zone V for soil type 1

5.2 Time history analysis results

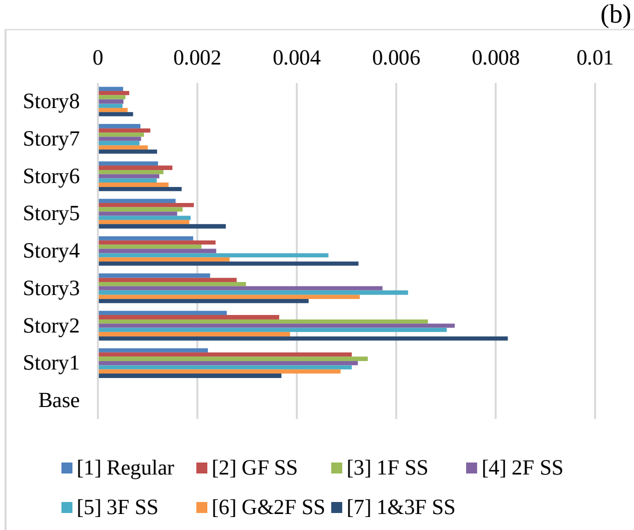
The most dependable and accurate analysis is the time-history analysis. Data from Chi-Chi, Imperial, Kobe, Landers, and Northridge were used for time history analysis, yielding peak ground acceleration values (PGA) of 0.0327, 0.0653, 0.138, 0.0898, and 0.0130. This ground motion data was provided by the pacific earthquake engineering research centre (PEERC) website (http://peer.berkeley.edu). With ETABS software, the data were matched to zone III, soil type 2.



(a)

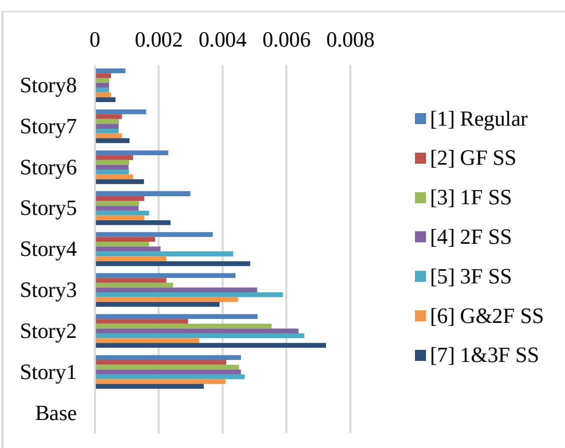


(b)

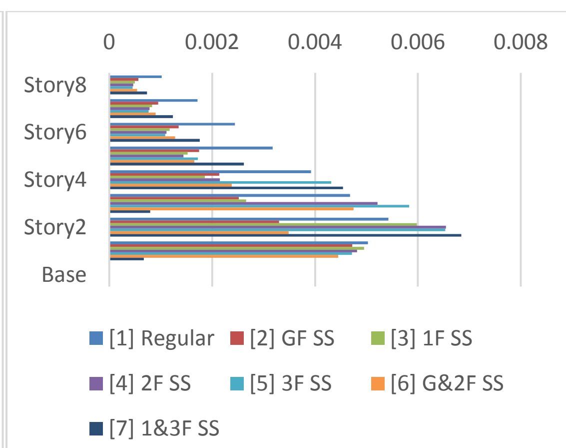


(c)

Figure 21 Storey drift in zone III, Zone IV and Zone V for soil type 2



(a)



(b)

Figure 22 Storey drift in zone III, Zone IV for soil type 3

Figure 23 shows the base shear variation for various notable ground motion records for typical building configurations. For the Kobe earthquake, GF SS model predicted a maximum base shear of 2946 kN. In spite of ground motion data, providing continuous soft storey results in higher base shear values.

As seen in *Figure 24*, displacements vary at various floors of buildings subjected to major earthquakes in the study. In spite of the ground motion record, soft storey played a critical role in the displacement of the numerous models involved. According to the Northridge Earthquake data, the highest storey displacement is 63.32 mm in the 3F SS model. Imperial and Kobe ground motion records produce slightly scattered results. This might be related to the fact that reported ground motion recordings show an increase in acceleration response.

Storey drift variation at various floors of typical building layouts evaluated in the study is shown in *Figure 25*. Drift variations in the study models were strongly affected by soft storeys, as well as displacement variation in various structural models. Northridge earthquake data showed a large storey drift of 0.005527.

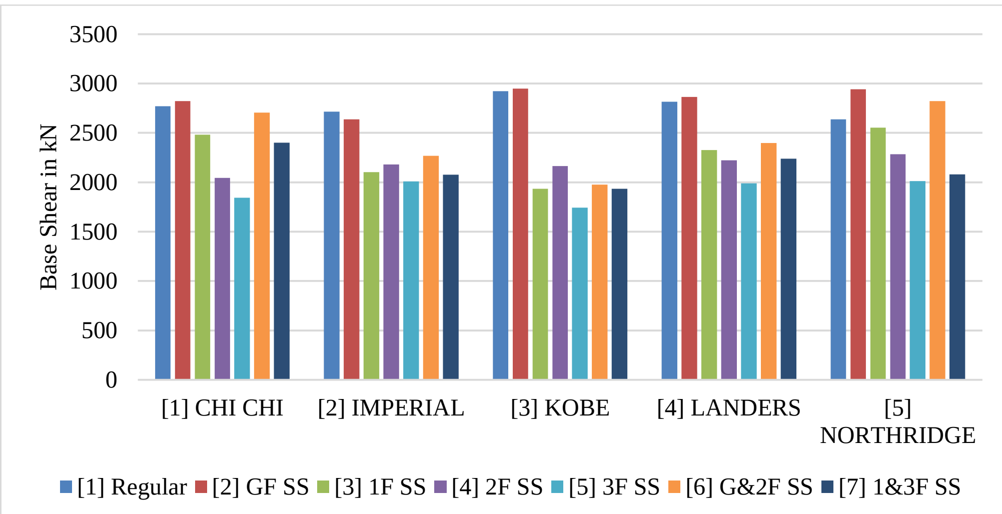
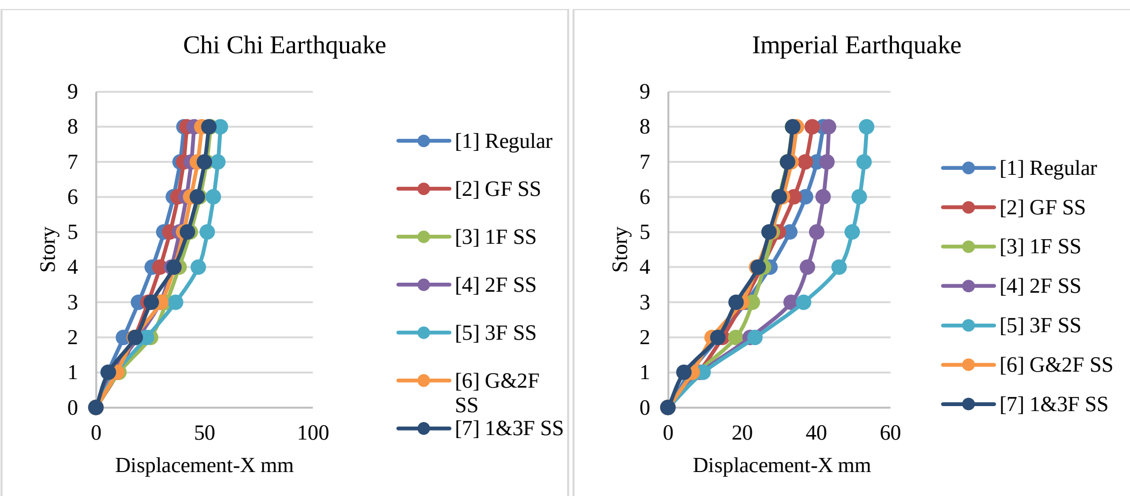


Figure 23 Base shear for various ground motions



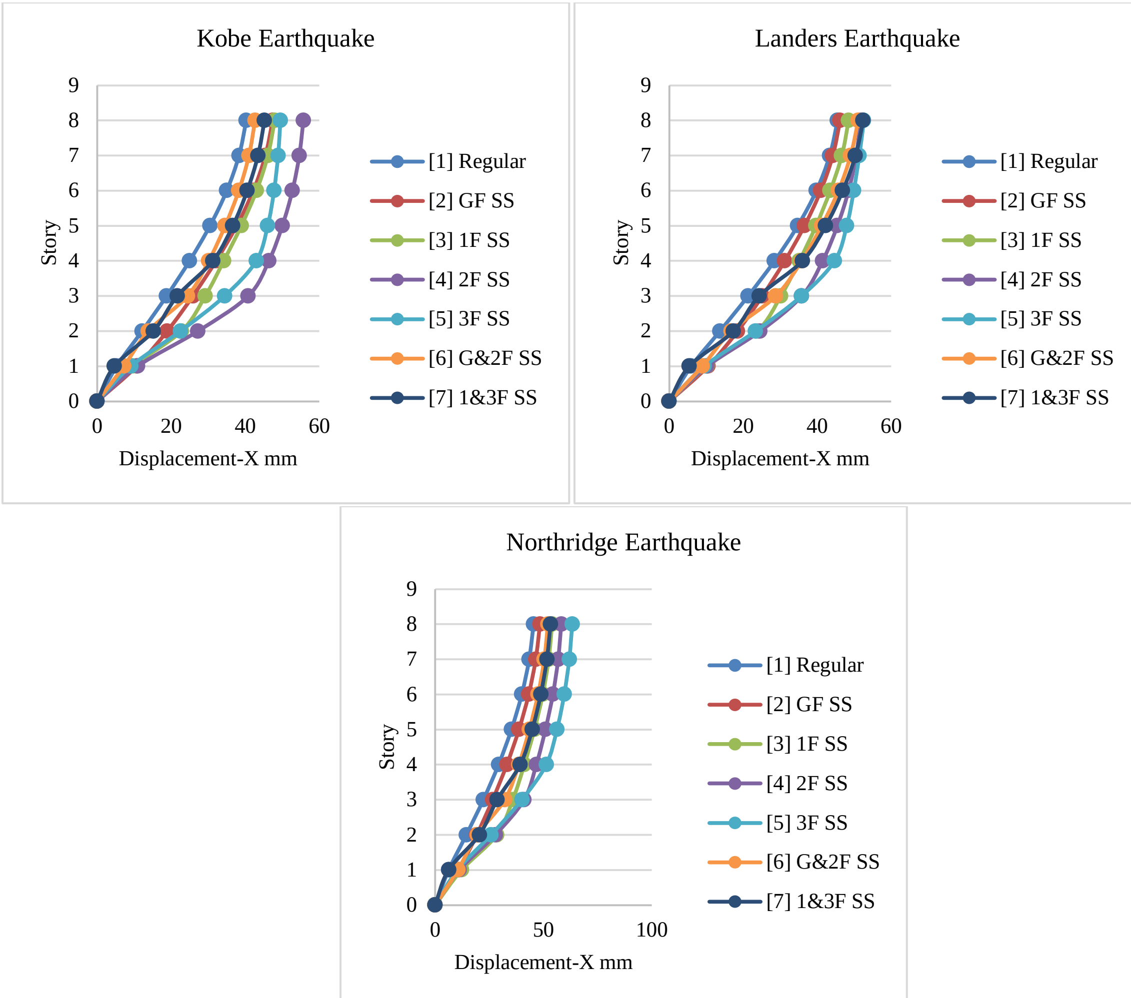
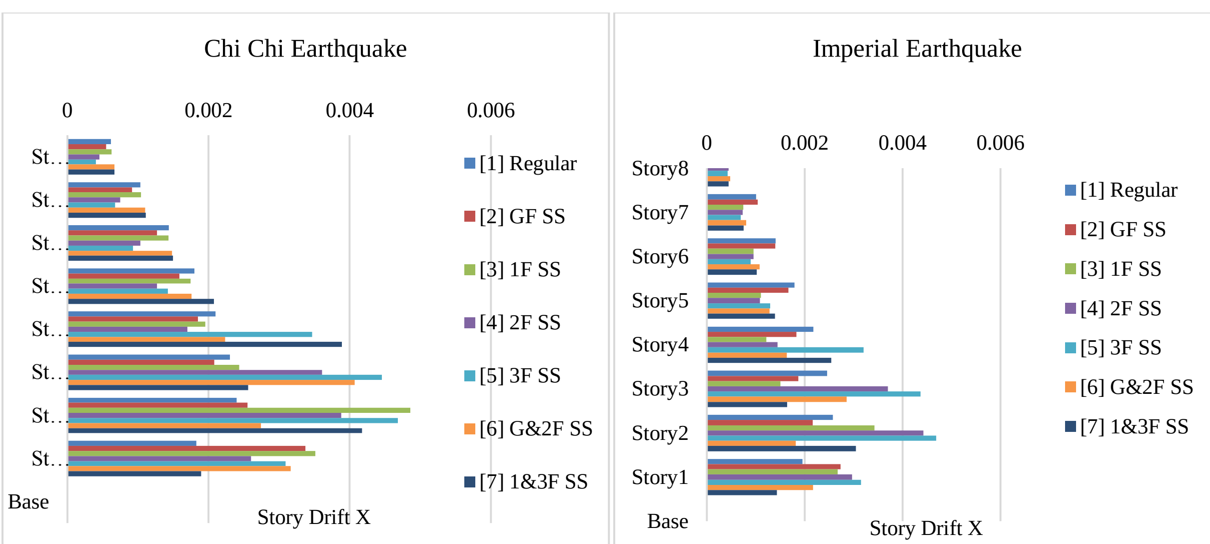


Figure 24 Storey displacement for various ground motions



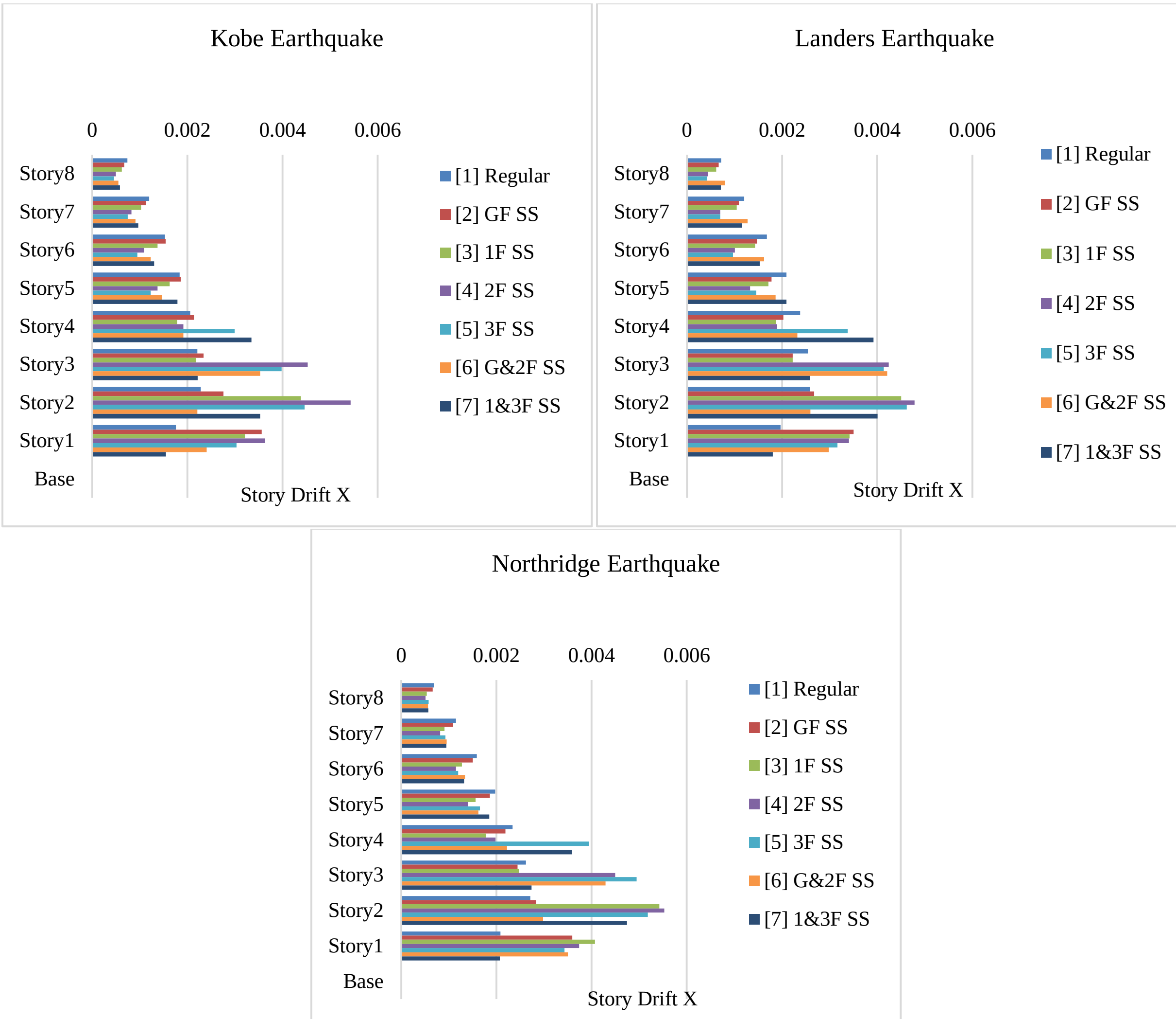


Figure 25 Storey drift for various ground motions

6.Discussion

In the case study buildings considered, seismic parameters such as base shear, storey displacement, and storey displacement are determined. FEMA 440 EL always yields higher base shear and displacement than ASCE 41-13. The reason is that FEMA 440 EL considers the force-displacement relation in both elastic and inelastic phases over the typical hinge patterns at every floor level, while ASCE calculates the target displacement at each floor level. Soft stories lead to a reduction in base shear. Displacement, however, rises with the number of soft stories. Due to the fact that, in the framed structures, the opening area increases when the soft storey is provided, so the lateral stiffness will also tend to decrease. The model with alternate soft storey (1&3F SS) shows significant inter-storey drift compared to other models with a value of 0.0082497. The reason for this is that by providing soft storeys on alternate floors, vertical rigidity (as well as lateral stiffness of the floors in between the soft storeys) is reduced. There is an incompatibility with Indian seismic code standards in upper bound values for narrative drift, which is also reflected in related literature. Storey displacement and shear increases with seismic zone change. The reason may be due to Indian seismic code that an increase in seismic zone as a function of earthquake magnitude tends to produce higher intensity of lateral forces acting on building frames at every floor level. Irrespective of the kind of building considered, this is true. In addition, storey displacements and shears were found to be higher in soft storey buildings. This lack of storey stiffness may be attributed to large open areas and soft storeys.

Soft storey played a crucial role in the displacement of numerous models despite the ground motion record. In contrast to the other notable earthquakes in the study, Imperial and Kobe ground motion records produce slightly scattered results. It could be related to the fact that recorded ground motions show an increase in acceleration response.

As a result, in the present study, it was found that vertical irregularity in mass can cause increased storey displacements and drifts, so provision of storey should be avoided when possible. For a realistic prediction, soil type should be considered when analyzing building frames for seismic performance. Structures with a higher seismic zone with soil type III result in large displacements and drifts, regardless of the building model. In the present seismic code, soil properties are neglected when accounting for seismic performance of structures, and this needs to be addressed.

6.1Limitations of the study

In the present study, a symmetrical building configuration was adopted to avoid torsional effects. Equivalent diagonal strut thickness is assumed to be equal to the infill wall thickness. Research was focused on seismic parameter prediction, such as storey displacement, storey shear, and drift. Response spectrum and time history analysis were employed in case study framed buildings of non-ductile type. In this study, the hysteric characteristics and acceleration responses of the ductility study aren't considered.

A complete list of abbreviations is shown in *Appendix I.*

7.Conclusion and future work

The following are the findings of the current research:

- Based on the masonry infill wall effect and analyzing the RC building using two non-linear methods, the earthquake damages in the soft stories of the building were accurately predicted.
- The current CSM and DCM evaluation techniques are straightforward. On the other hand, DCM (ASCE 41) produces lower seismic responses than CSM (FEMA 440 EL) in the current example MRFs.
- ASCE 41-13 consistently yields lower displacement and base shear than FEMA 440 EL.
- Plastic hinges clearly illustrate the collapse mechanism. The first hinges were formed at the base level columns, and then crossed the collapse prevention (CP) level [50].
- The base shear decreases as the number of soft stories increases at the performance level, whereas displacement increases.
- Based on the results of the time history analysis, the PBSE method is superior; therefore, the next generation PBSE methodology can be considered consistent with the time history analysis results.
- At critical stages, these measures are effective in calculating element deformations and displacements, but not for assessing the degree of damage or the risk of collapse. As part of the FEMA 445 development process, it is necessary to express performance goals linked to stakeholders' primary concerns (viz., repair cost, casualty rate, and downtime). When evaluating performance, the damage index (DI) should be considered.

Multi storey structures can be evaluated based on damage indices for each performance level in the future. Furthermore, different soil types and earthquake severity can be accounted for. In addition to performance based evaluation, irregularity and other lateral load resisting systems need to be considered.

Acknowledgment

The contribution of each author is equally acknowledged. The present study is not a part of any funded project from any funding agency. The authors would like to acknowledge Mohammed Fairoz, Postgraduate Student of NMAMIT, Nitte, for his contribution.

Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Ranjith A: Conceptualization, investigation, writing – original draft, Study conception, supervision. **Kiran B M:** Writing-review and editing. **Sanjith J:** Analysis and interpretation of results. **Mahesh Kumar C L:** Draft manuscript preparation. **Shwetha K G:** Review information collecting and writing.

References

[1] Choudhari JD, Chopade NN. Performance based seismic design of RC building with consideration of soil structure interaction. International Research Journal of Engineering and Technology. 2018; 5:2139-47.

[2] Mabood A, Zameerruddin M, Shimpale PM. Performance-based seismic evaluation of vertically irregular moment resisting reinforced concrete frames using nonlinear statics analysis. International Journal of Civil Engineering. 2021; 8(6):8-19.

[3] Kumar A, Mavani S. Performance based seismic assessment of high-rise RC buildings. International Journal of Advances in Mechanical and Civil Engineering. 2021; 8(2):8-11.
[4] Sung YC, Liao WI, Yen WP. Performance-based concept on seismic evaluation of existing bridges. Earthquake Engineering and Engineering Vibration. 2009; 8(1):127-35.
[5] Ghobarah A. Performance-based design in earthquake engineering: state of development. Engineering Structures. 2001; 23(8):878-84.
[6] Khedkar AS, Dubal AR, Vasanwala AS. Performance based seismic design of reinforced concrete moment resistant frame with vertical setback. International Journal of Engineering Research & Technology. 2014; 3(2).
[7] Hamburger R, Rojahn C, Moehle J, Bachman R, Comartin C, Whittaker A. The ATC-58 project: development of next-generation performance-based earthquake engineering design criteria for buildings. In 13th world conference on earthquake engineering 2004 (pp. 1-15).
[8] Priestley MJ. Performance based seismic design. Bulletin of the New Zealand Society for Earthquake Engineering. 2000; 33(3):325-46.
[9] Mehare PS, Joshi MM. Performance based seismic design of RCC building. International Journal of Progressive Research in Science and Engineering. 2021; 2(7):80-3.
[10] Priestley MJ. Displacement-based seismic assessment of reinforced concrete buildings. Journal of Earthquake Engineering. 1997; 1(1):157-92.
[11] Moehle JP. Displacement based design of RC structures. In proceedings of the tenth conference on earthquake engineering 1992 (pp. 4297-302).
[12] Chintanapakdee C, Chopra AK. Evaluation of modal pushover analysis using generic frames. Earthquake Engineering & Structural Dynamics. 2003; 32(3):417-42.
[13] American Society of Civil Engineering. Seismic rehabilitation of existing buildings. American Society of Civil Engineers. 2007.
[14] Pekelnicky R, Engineers SD, Chris PSE, Engineers ND. ASCE 41-13: seismic evaluation and retrofit rehabilitation of existing buildings. Proceedings of the SEAOC. 2012.
[15] https://www.atcouncil.org/pdfs/atc40toc.pdf. Accessed 24 May 2022.
[16] Council BS. FEMA 273–NEHRP guidelines for the seismic rehabilitations of buildings. Federal Emergency Management Agency, Washington (DC). 1997.
[17] Pre-standard FE. Commentary for the seismic rehabilitation of buildings, report FEMA-356. Washington, DC: SAC Joint Venture for the Federal Emergency Management Agency. 2000.
[18] FEMA-440, Improvement of nonlinear static seismic analysis procedures. FEMA-440, Redwood City. 2005; 7(9):11.
[19] FEMA F. 445. Next-generation performance-based seismic design guidelines program plan for new and existing buildings. Redwood City. 2006.
[20] Freeman SA. Performance-based seismic engineering: past, current, and future. In structures congress 2000 2000.
[21] Zameeruddin M, Sangle KK. Performance-based seismic assessment of reinforced concrete moment resisting frame. Journal of King Saud University-Engineering Sciences. 2021; 33(3):153-65.
[22] https://www.iitk.ac.in/ce/test/IS-codes/is.456.2000.pdf. Accessed 24 August 2022.
[23] Rehan M, Azam F. Performance based design of RCC structure. International Journal of Advance Research, Ideas and Innovations in Technology. 2018; 4(4):1059-63.
[24] Ingale C, Nalamwar MR. Performance based seismic design of RCC building. International Research Journal of Engineering and Technology. 2017; 4(10):618-23.
[25] Naik P, Annigeri S. Performance evaluation of 9 storey RC building located in North Goa. Procedia Engineering. 2017; 173:1841-6.
[26] Noh NM, Aznin NI, Zin MH, Ghari MA, Zahari MA, Rushdi MF. Seismic assessment of reinforced concrete frame with unreinforced masonry infill walls in Malaysia. In proceedings of the 5th international conference on sustainable civil engineering structures and construction materials 2022 (pp. 379-90). Springer, Singapore.
[27] Demir A. Investigation of the effect of real ground motion record number on seismic response of regular and vertically irregular RC frames. Structures. 2022; 39: 1074-91. Elsevier.
[28] Leti M, Bilginb H. Damage potential of near and far-fault ground motions on seismic response of RC buildings designed according to old practices. Research on Engineering Structures and Materials. 2022; 8(2):337-57.
[29] Demirel IO, Yakut A, Binici B. Seismic performance of mid-rise reinforced concrete buildings in Izmir Bayrakli after the 2020 Samos earthquake. Engineering Failure Analysis. 2022.
[30] Sarvade RD, Kulkarni SK. Analytical study on storey shear and base shear of H shape and step back set back multistoried buildings on sloping ground. International Journal of Innovative Research in Technology. 2022; 8(10):593-7.
[31] Patil ST, Chavan MA. A comparative study on dynamic analysis of multi-storied building (G+24) with vertical irregularities. International Research Journal of Engineering and Technology. 2022; 9(3):1983-6.
[32] Mouhine M, Hilali E. Seismic vulnerability assessment of RC buildings with setback irregularity. Ain Shams Engineering Journal. 2022; 13(1).
[33] Miari M, Jankowski R. Seismic gap between buildings founded on different soil types experiencing pounding during earthquakes. Earthquake Spectra. 2022; 38(3):2183-206.

[34] Lehman D, Moehle J, Mahin S, Calderone A, Henry L. Experimental evaluation of the seismic performance of reinforced concrete bridge columns. Journal of Structural Engineering. 2004; 130(6):869-79.
[35] Zou XK, Chan CM. Optimal seismic performance-based design of reinforced concrete buildings using nonlinear pushover analysis. Engineering Structures. 2005; 27(8):1289-302.
[36] Ali RK. Evaluation of various methods of FEMA356 compare to FEMA440. Journal of Civil Engineering and Construction Technology. 2013; 4(2):51-5.
[37] Akkar S, Metin A. Assessment of improved nonlinear static procedures in FEMA-440. Journal of Structural Engineering-Asce. 2007; 133(9):1237-46.
[38] Saleemuddin M, Mohd Z, Sangle KK. Seismic damage assessment of reinforced concrete structure using non-linear static analyses. KSCE Journal of Civil Engineering. 2017; 21(4):1319-30.
[39] Mathieu GO, Abdullah AS, Saad LA. Performance-based seismic design for buildings. Structural Mechanics of Engineering Structures and Structures. 2020; 16(2):161-6.
[40] Inel M, Ozmen HB. Effects of plastic hinge properties in nonlinear analysis of reinforced concrete buildings. Engineering Structures. 2006; 28(11):1494-502.
[41] De RMT, Di DM, Ricci P, Verderame GM, Manfredi G. Experimental investigation on the influence of the aspect ratio on the in-plane/out-of-plane interaction for masonry infills in RC frames. Engineering Structures. 2019; 189:523-40.
[42] Dolšek M, Fajfar P. The effect of masonry infills on the seismic response of a four-storey reinforced concrete frame-a deterministic assessment. Engineering Structures. 2008; 30(7):1991-2001.
[43] Furtado A, Rodrigues H, Arêde A, Varum H. Influence of the in plane and out-of-plane masonry infill walls' interaction in the structural response of RC buildings. Procedia Engineering. 2015; 114:722-9.
[44] Hashemi SA. Seismic evaluation of reinforced concrete buildings including effects of masonry infill walls. University of California, Berkeley; 2007.
[45] Agrawal P, Shrikhande M. Earthquake resistant design of structures. PHI Learning Pvt. Ltd.; 2006.
[46] Ozkaynak H, Yuksel E, Yalcin C, Dindar AA, Buyukozturk O. Masonry infill walls in reinforced concrete frames as a source of structural damping. Earthquake Engineering & Structural Dynamics. 2014; 43(7):949-68.
[47] Ricci P, Di DM, Verderame GM. Experimental assessment of the in-plane/out-of-plane interaction in unreinforced masonry infill walls. Engineering Structures. 2018; 173:960-78.
[48] Standard I. Criteria for earthquake resistant design of structures. Bureau of Indian Standards, Part. 1893.
[49] Peters TF. International association for bridge and structural engineering: the first 80 years 1929-2009. IABSE; 2011.
[50] Pavithra R, Prakash DT. Study of behavior of the soft stories at different locations in the multi-story building. International Journal of Engineering Research & Technology. 2018; 7(6):53-9.
[51] Tiwari P, Salunke PJ, Gore NG. Earthquake resistant design of open ground storey building. International Research Journal of Engineering and Technology. 2015; 2(7): 63-71.
[52] Yoshimura M. Nonlinear analysis of a reinforced concrete building with a soft first story collapsed by the 1995 Hyogoken-Nanbu Earthquake. Cement and Concrete Composites. 1997; 19(3):213-21.

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Appendix I

S. No.	Abbreviation	Description
1	ASCE	American Society of Civil Engineers
2	ATC	Applied Technology Council
3	CP	Collapse Prevention
4	CSM	Capacity Spectrum Method
5	DBSD	Displacement Based Seismic Design
6	DCM	Displacement Coefficient Method
7	DI	Damage Index
8	EQVT	Equivalent Diagonal Strut
9	ETABS	Extended Three-Dimensional Analysis of Building Systems
10	FEMA	Federal Emergency Management Agency
11	FF	Ground floor
12	MDOF	Multi-Degree of Freedom
13	MRF	Moment Resisting Frame
14	PA	Pushover Analysis
15	PBSD	Performance -Based Seismic Design
16	PBSE	Performance Based Seismic Evaluation
17	PEERC	Pacific Earthquake Engineering Research Centre
18	PGA	Peak Ground Acceleration
19	PP	Performance Point
20	RC	Reinforced Concrete
21	SDOF	single Degree of Freedom
22	SRSS	Square Root of Sum of Squares
23	SS	Soft Storey
24	STAAD	Structural Analysis and Design
25	URM	Unreinforced Masonry